

Mergers and star formation in SPH cosmological simulations

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Abstract. The star formation rate history of galactic objects in hydrodynamical cosmological simulations are analyzed in relation to their merger histories. The findings suggest that massive mergers produce more efficient starbursts and that, depending on the internal structure of the objects, double starbursts could also occur.

Our knowledge of the Universe has dramatically improved in the last decade thanks to the large amount of information gathered on nearby and high redshift objects that makes possible to attempt tests of theoretical models on more realistic basis. Galaxies surveys have been produced and used to try to test structure formation scenarios and cosmological models. However, a main problem in these studies is the relationship between galaxies and the underlying overall mass distribution: do galaxies trace the mass? or how galaxies trace the mass? In particular, it is now known that clustering properties of galaxies depend, at least, on their color and luminosities. And that, selection effects and galaxy formation conspire to bring different types of galaxies into the samples as function of the z . Hence, understanding the clustering properties at different z implies being able to explain how galaxy formation proceeds within dark matter halos. At high z , Lyman Break Galaxies (LBG) have provided us with information of objects in the early phase of evolution of the Universe. These objects have been found to be strongly clustered. The good agreement found between both abundance and clustering properties of massive dark matter halos and typical LBGs have led to support the idea that star formation is mainly determined by gas accretion onto the potential well of halos (i.e., Aldelberger et al 1998). However, assuming a hierarchical clustering scenario for the formation of the structure brings mergers and interactions into play as common events in the formation and evolution of galaxies, making the picture more complex.

The observed astrophysical properties of galactic objects depend on their star formation (SF) histories. Since SF is a complex mechanism regulated by different physical processes acting at different scales such as supernova feedback, gas cooling, interactions, mergers, disk instabilities, etc., its link with mass may be not straightforward. Violent event may play an important role in the SF histories of a galactic object. Indeed, observations of nearby and high- z objects suggest an increment of both, the SF activity and the rate of mergers with z . From a theoretical point of view, several authors have studied their effects on the SF history of galaxies by using prepared merger simulations (i.e., Mihos & Hernquist 1996; Barnes & Hernquist 1996) or introducing their effects in semianalytical models (Kauffman et al. 1993; Somerville & Primack 1998; Percival & Miller 1999). In this work, I present results on a detail analysis

of the star formation history of typical galaxy-like objects in relation to their merger history in hydrodynamical simulations within a cosmological context.

1. Simulations

The simulations analyzed in this work are described in details by Tissera (1999). Briefly, they take into account the gravitational and hydrodynamical evolution of the matter including an algorithm to transform cold and dense gas into stars. All experiments are consistent with a standard Cold Dark Matter universe. The simulated boxes have $5h^{-1}$ Mpc length with $N = 64^3$ total particles. Baryonic particles represent 10 % of the total mass. Note that dark matter and baryonic particles have the same mass, $M_{\text{part}} = 2.6 \times 10^8 M_{\odot}$. We run three simulations, S.1, S.2 and S.3. Simulations S.1 and S.2 share the same initial conditions while S.3 is a different realization. The bias parameter b for S.1 and S.2 is $b = 2.5$, and for S.3, $b = 1.67$.

The star formation algorithm is based on the Schmidt law: $\dot{\rho}_{\text{star}} = -c\rho_{\text{gas}}/t_*$, where c is the star formation efficiency ($c = 0.01, 0.1, 0.01$ for S.1, S.2 and S.3, respectively) and t_* is a characteristic time-scale assumed to be equal to the dynamical time of the particle. There is another parameter T_* which is the critical temperature for gas particles to be transformed into stars: $T_* = 10^4$ K and 3×10^4 K for S.1 and S.2, and S.3 respectively. The values of c and T_* together with b affect the SF in the simulated box. Globally, simulations S.1, S.2 and S.3 have transformed 12%, 28% and 7.5%, respectively, of their total baryonic mass into stars at $z = 0$. The SF parameters used in S.1 and S.3 allow the transformation of gas into stars only in the very dense regions. In practice, this fact implies that gas particles have to get to the center of the progenitor before can be converted into stars. Supernova feedback has not been included in these simulations.

2. Mergers and Star Formation History

Galactic-like objects (GLO) are identified at their virial radius at $z = 0$ and then, followed back in time. Their merger trees are reconstructed by tracking back all particles that belong to a given GLO at $z = 0$, and the progenitor object is chosen as the more massive clump within this merger tree. We consider mergers with clumps larger than 10% the progenitor virial mass at the time of the merger. We will define a merger event as the whole process from the time the two objects are first identified to share the same dark matter halo, to the time there two baryonic clumps merged. During the orbital decay phase, the minor colliding baryonic clump will be refereed as the satellite. It has to be stressed that we are only going to study those GLOs with more than 250 baryonic particles inside the main object and from $z = 1$, to diminish as much as possible numerical resolution effects.

The SF rate history of each GLO is estimated by reckoning the stellar mass formed in its progenitor objects at each z and, then, smoothing these distributions over time. In Fig.1 we show the mean SFR histories for GLOs 2 and 3 in S.1 as a function of look-back time. The arrows pointing up indicate the times at which the satellite enters the virial radius of the progenitor, while the

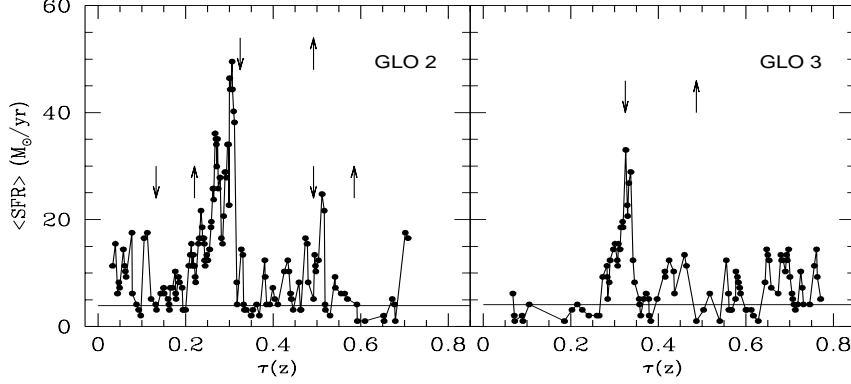


Figure 1. Star formation history of galaxy-like objects in simulation S.1 as a function of look-back time. Merger events are indicated by arrows

actual fusion of the baryonic clumps is indicated by the arrows pointing down. As can be seen from this figure, there is an increase of the SF activity during the merger events. This situation is common to all GLOs analyzed.

In order to identify more rigorously the SFR peaks, we estimate the overall minimum SFR in a GLO at any redshift. We then subtract a factor f of this minimum from the total SFR history, so that peaks are clearly identified as the values with a signal larger than a threshold δ_{\min} (solid line in Fig.1). We took $f = 3$ for all GLOs, which yields mean values of $\langle \delta_{\min} \rangle = 0.90, 1.45, 0.89 \text{ M}_{\odot}/\text{yr}$ for GLOs in S.1, S.2 and S.3, respectively. Hence, all SFR history can be described as the contribution of two components: a quiescent SF and a series of starbursts (SB). From all SBs identified, we are only concern with those that occurred within a merger event. Once the starbursts are isolated, it is direct to define their height, σ_{star} , the total stellar mass formed, M_{burst} , and their duration, τ_{burst} . Table 1 shows their mean values in units of $\text{M}_{\odot}/\text{yr}$, 10^8yr and 10^{10}M_{\odot} , respectively. These quantities determine the characteristics of each starburst together with the gas richness of the system, $M_{\text{star}}/M_{\text{bar}}$, and the virial mass ratio of the colliding objects, $M_{\text{sat}}/M_{\text{pro}}$, at the time of the merger. M_{star} and M_{bar} are the stellar and baryonic content of the merging systems; M_{sat} and M_{pro} are the virial masses of the satellite and progenitor, respectively.

Table 1. Mean values for the parameters of the stellar bursts.

S	$\langle \sigma_{\text{star}} \rangle$	$\langle \tau_{\text{burst}} \rangle$	$\langle M_{\text{burst}} \rangle$
1	20.79	9.28	1.36
2	40.02	11.49	1.79
3	12.51	5.14	0.39

An exhaustive analysis of the properties of the SBs yields the following conclusions. We found no correlation between σ_{star} and $M_{\text{sat}}/M_{\text{pro}}$. Mergers with equal $M_{\text{sat}}/M_{\text{pro}}$ are found to produce SBs of different strengths. A study of σ_{star} versus the gas richness of the systems defined by $M_{\text{star}}/M_{\text{bar}}$ shows no correlation indicating that not always the more gas-rich object have the larger

σ_{star} and that equal gas-rich GLOs have different σ_{star} , even within the same simulations. Hence, the fact that equal massive mergers produce different σ_{star} bursts in the same simulations can not be directly linked to a difference in the gas richness of the systems.

We also found that σ_{star} shows no correlation signal with neither M_{gas} nor M_{pro} . Distinguishing between minor and major mergers ($M_{\text{sat}}/M_{\text{pro}} = 0.35$) suggests that minor mergers can trigger bursts as strong as major ones even if the systems are less gas-rich. On the other hand, no correlation signal was found between neither M_{burst} and M_{gas} nor M_{burst} versus $M_{\text{star}}/M_{\text{bar}}$. However, a trend was found for major mergers to be more efficient at transforming gas into stars during mergers. This fact can be seen in Fig.2a where we plot SB efficiencies $M_{\text{burst}}/M_{\text{gas}}$ versus $M_{\text{sat}}/M_{\text{pro}}$ for bursts in S.1 (circles), S.2 (triangles) and S.3 (pentagons). Mean values of SB efficiencies for minor mergers ($M_{\text{sat}}/M_{\text{pro}} < 0.35$) are 0.24, 0.23 and 0.10 in S.1, S.2 and S.3 respectively, while for major ones: 0.35, 0.72 and 0.19, respectively.

During the inspection of the starbursts, it was also found that during certain mergers events, two double peaks were identified: a first one during the orbital decay phase of the satellite, and, a second one during the fusion of the baryonic cores. As have been reported by Mihos & Hernquist (1996) and Dominguez-Tenreiro, Tissera, Sáiz (1998) among others, the presence of the first SB could be related to the stability properties of the gaseous disks. This authors found that the presence of a compact stellar bulge assures the stability of gaseous disks during violent events preventing the triggering of strong gas inflows during the orbital decay phase. These tidal induced inflows could be related to the presence of the first SB (see Tissera et al. 2000 for details). In this sense, we look for a correlation between the presence of these double starbursts and the formation of a compact stellar mass concentration (i.e., as an indicator of the formation of a compact stellar bulge). We measured the heights of the bursts and ratio between the stellar content of the progenitor at the time the satellite enters its virial radius and the progenitor total stellar mass at $z = 0$ ($M_{\text{star}}^z/M_{\text{star}}^0$). This ratio gives a rough idea of the presence of a well-formed stellar mass concentration at the center. Fig.2b shows this relation. As can be clearly seen, we only detect double bursts in those GLOs with $M_{\text{star}}^z/M_{\text{star}}^0 < 0.40$. All GLOs with $M_{\text{star}}^z/M_{\text{star}}^0 > 0.40$ have only single bursts when the fusion of the baryonic clumps occurs. It has to be mentioned that $\sigma_{\text{star}}^1/\sigma_{\text{star}}^2$ does not correlate with either, $M_{\text{star}}/M_{\text{bar}}$ or M_{gas} . Looking at the starburst efficiencies of these double events, we found a trend for first SB to be more efficient than single ones. The mean value for mergers in S.1, S.2 and S.3 are: (0.39,0.08), (0.56,0.39) and (0.16,0.03) for starbursts with $M_{\text{star}}^z/M_{\text{star}}^0$ smaller and greater than 0.40, respectively (Tissera et al. 2000).

3. Summary

Using hydrodynamical simulations in a cosmological context has allowed us to consistently study the star formation and merger histories of galactic objects. Our findings suggest that, if a hierarchical clustering scenario is adopted, mergers and interactions play a critical role in the regulation of star formation since they are able to violently compressed the gas in short time-scales. Given the Schmidt

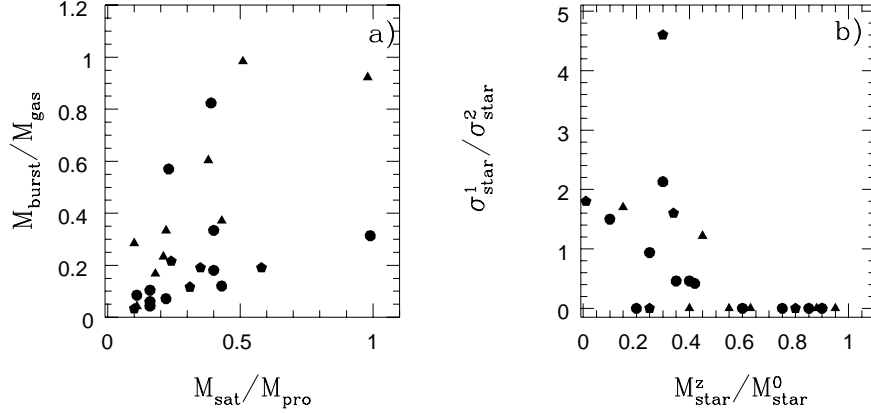


Figure 2. a) Starburst efficiency versus the relative virial masses of the colliding systems. A trend is found for more massive mergers to produce more efficient bursts. b) Ratio between the strengths of the double star bursts ($\sigma_{\text{star}}^1/\sigma_{\text{star}}^2$) and the fraction of stars already formed in the progenitor ($M_{\text{star}}^z/M_{\text{star}}^0$) at the z of the merger ($z_1 > z_2$). Single bursts have been assigned $\sigma_{\text{star}}^1/\sigma_{\text{star}}^2 = 0$.

law, any increase in the gas density would lead to an increase in the SF rate. Hence, how baryons distribute within the dark matter halos seems to be relevant for the SF process. Even more, how the systems behave during violent events could also depend on its internal structure might have a non-negligible effect on SF. And, since properties of galactic objects change with time as they evolve, how the same physical mechanisms affect star formation might also change with z making it difficult to establish a direct link between mass and star formation.

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